Naval Research Laboratory
Washington, DC 20375-5320

NRL/MR/5309--97-7914

RADARC Evaluation ROTHR Data: Winter, Spring, and Summer 1994

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February 28, 1997

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 28,1997	

4. TITLE AND SUBTITLE

RADARC Evaluation
ROTHR Data: Winter, Spring, Summer 1994

5. FUNDING NUMBERS

PE - O&MN
DN291-215

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/5309--97-7914

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Space Command
Dahlgren, VA 22448-5170

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Lucas Radio

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (*Maximum 200 words*)

We find that the RADARC skywave radar estimation model in its simplest form provides received power level behavior that correlates well with observed received signal strengths from short to moderate one-hop distances. Correspondence generally decreases with increasing range. Environmental noise from the model is similar to that observed. Spread-in-Doppler clutter (SDC), as an addition to the passive environmental noise level, frequently degrades performance. The RADARC version used did not predict the SDC observed, and the incorporation of a validated SDC model is where a major improvement in prediction can be implemented. The radar data we have used here employed a ten waveform repetition rate (WRF), and therefore indicated the performance to be expected when using the low WRF modes with no ambiguous range folding. However, although not exhibited in this study, we need improved very long range propagation predictions to account for ambiguous SDC.

14. SUBJECT TERMS

Ionospheric models
OTH radar
Skywave transmission

15. NUMBER OF PAGES

14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

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RADARC EVALUATION
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Introduction

Our effort in this report is directed toward showing how our RADARC HF radar model compares with ROTHR radar data on a structural basis, that is, how does our model which is monthly median compare with daily observations. This is in contrast with prior quasi-statistical studies that have compared model products with the medians of a set of observations *(Headrick and Root 1993)*. Model agreement with medians of data is a reasonable method to rate model validity, but it can fail to indicate the reasons for failure. We wish to identify specific model features that need improvement. The data used is from the Virginia ROTHR, once a week, diagnostic collection as reduced and displayed by Root *(Root 1994)*. The periods covered are winter, equinox (spring), and summer of 1994. The sea surface backscatter is used as the reference target in effecting comparisons. The radar location and the nominal surveillance area are shown in Figure 1. Data from the boresight to plus eight degrees sector was used.

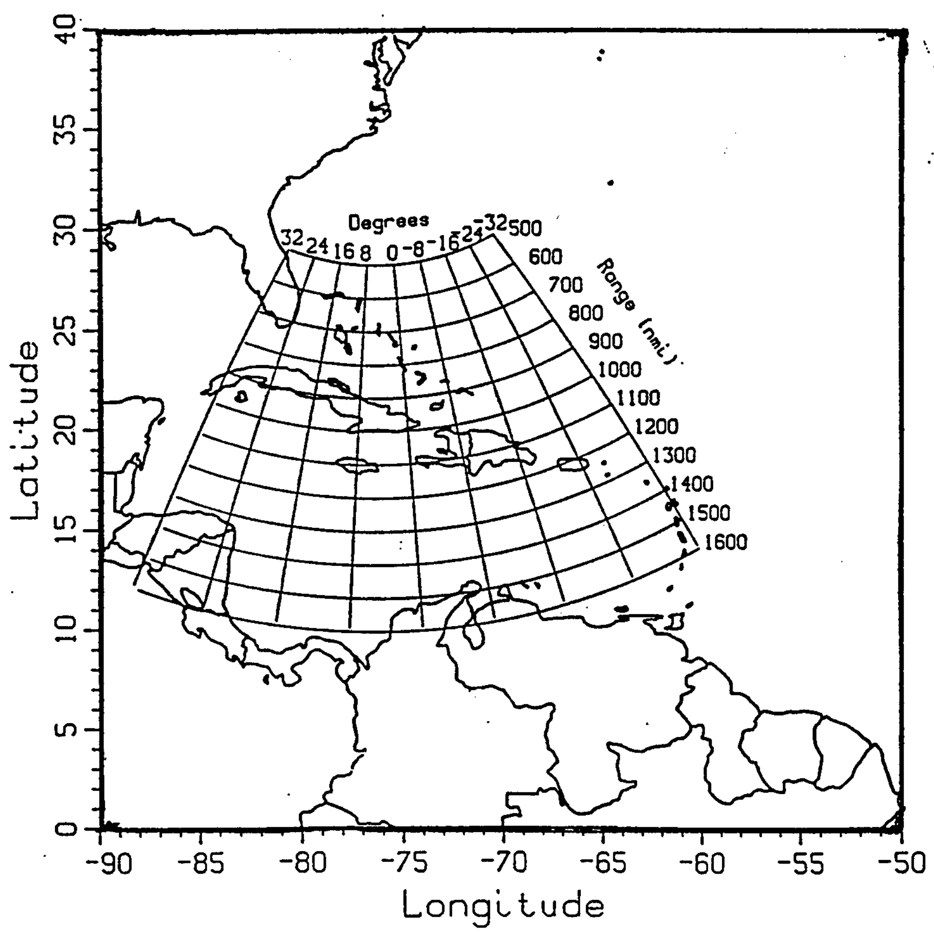


Figure 1. The nominal normal area coverage is given, 500 to 1600 nmi and plus and minus 32 degrees from boresight, 175 T.

Manuscript approved January 21, 1997

About the Model

The RADARC model consists of the following separable components: (one) an earth-ionosphere cavity transmission medium description in the form of either virtual o true electron density heights; (two) geometric radiowave path trace methods; (thre a radar equation; and (four) noise tables. The geometry is fully spherical with electron densities varying in both the vertical and horizontal and with time. The transmission medium or ionosphere description is based upon past empirical observations, principally ionosonde data and path loss measurements.

The radar equation used is standard and in dB form is:

SNR = PWR + GtGr + LAMLOG + CIT + CAREA or TAREA + OTH
-R4TH - TLOSS - SYSLOS - NOISE

PWR = average transmitter power.

GtGr = the transmitter and receiver antenna gain product.

LAMLOG = wavelength squared divided by four pi cubed.

CIT = coherent processing time in seconds.

CAREA or TAREA = radar cross section (RCS).
-For the sea echo this is the resolution cell area surface scattering coefficient product.
-For aircraft and missiles it is the free space RCS.

OTH = the skywave paths constructive interference enhancement.
-For the sea echo (CAREA) this is 12 dB.

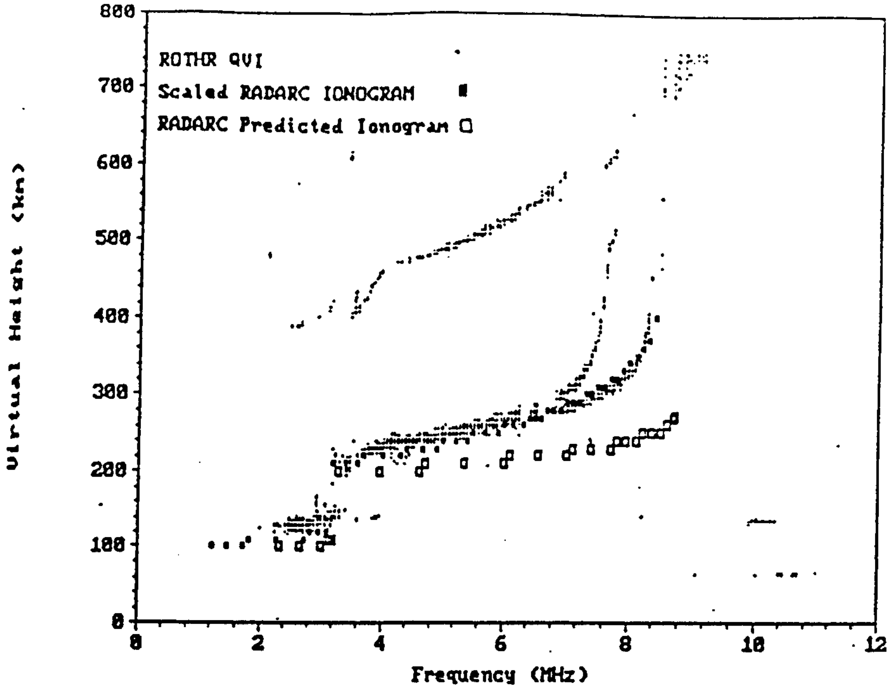
R4TH = distance to the forth power.
-The trajectory is determined by the path trace method.

TLOSS = Ionospheric path and ground reflection losses that are determined by tl path trace technique.

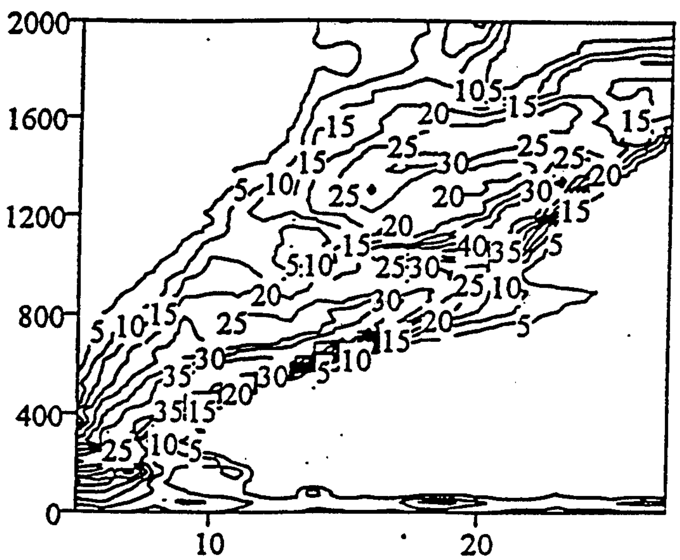
SYSLOS = processing and other losses whose effect is the equivalent to a reduction in transmitter power.

A closed form virtual height path trace or a true height ray trace are available. Both of these geometric methods fail to treat adequately the transition from the skip zone to illumination region. However the virtual height method used (*Lucas e al 1993*) has an 'above the MUF treatment' added that provides an approximation fo this transition region, and it is used in this study. Also, the geometric path methods have an abrupt cut off at the horizon that does not correspond with observation. Transmission losses are determined as part of the path determinatior

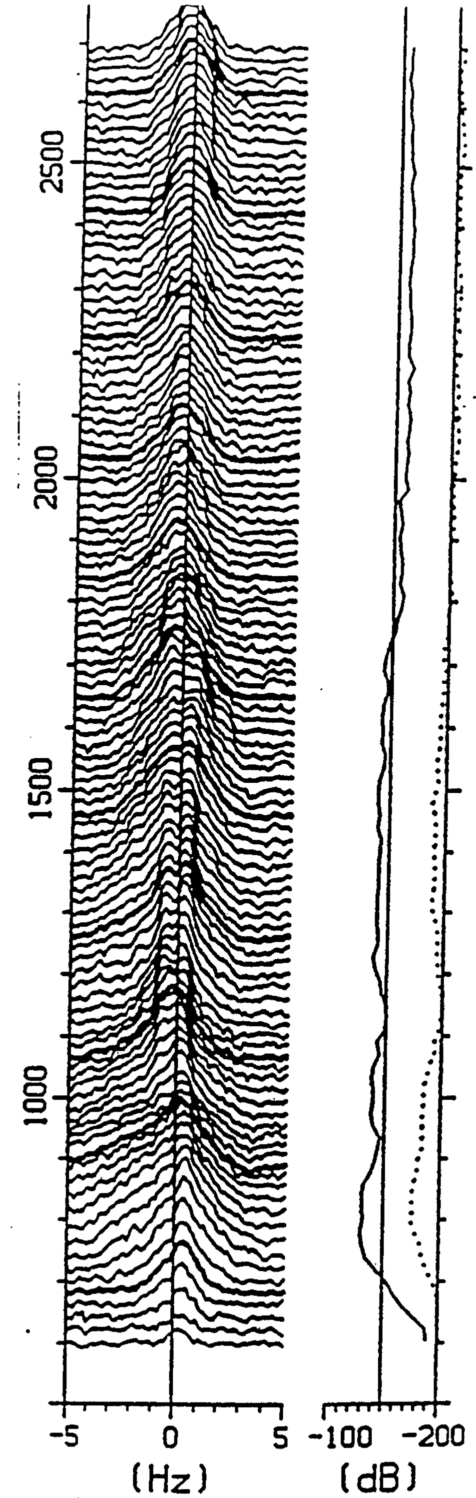
The noise can be selected from: atmospheric and galactic as provided by CCIR 322 (*1988*); a site noise estimate addition; a receiver front end noise addition; or SDC model addition.



(a) The quasi-vertical sounding is shown for: ROTHR as dots; RADARC's median predicted ionogram as open box points; and the RADARC prediction after critical frequency and height correction as solid boxes.



(b) A wide sweep backscatter sounder ionogram is plotted as db contours of clutter-to-noise ratio in virtual range (nmi) - frequency (MHz) space.



(c) A Amplitude-Range-Doppler radar map is given on the left and on the right the peak and 2.5 Hz levels.

Figure 2. Examples of available data formats are given for 2 January 1994 18Z.

Some factors that can bias the model output should be mentioned. GtGr values are estimates not measured values. SYSLOSS (System losses) are an uncertain quantity. CAREA (sea surface RCS) which is frequently assumed constant is only approximately constant at best and is difficult to estimate accurately.

About the Data

The data used is from Root's (Root 1994) extraction, reduction, and analysis of ROTHR Virginia tapes. These come from once a week records made for diagnostics an documentation. The calendar interval was January through June 1994, that is winter, vernal equinox, and summer. The data is comprised of quasi-vertical ionograms (QVIs), wide sweep backscatter ionograms (WSBIs), and amplitude-range-Doppler (ARD) maps with examples shown in Figures 2a, 2b, and 2c respectively. Th QVI is at the radar site. The WSBIs oblique backscatter is from about 8 degrees beamwidth and over 5 to 28 MHz. And the ARD map uses the entire radar capability but is for the single frequency selected by the radar operator.

The ARD map is the output that is definitive in display of radar performance, and in our data is the smoothed average over 16 receive beams with 6 seconds coherent processing. For Figure 2c in addition to the amplitude versus Doppler spectra versus range, the maximum clutter level and WRF/4 level have been plotted; where there is no or little backscatter this WRF/4 level can be taken to be environmenta noise free of SDC. This clutter-to-noise (CNR) is a true performance indicator, b the maximum clutter and WRF/4 levels are as read from the data tape and must be adjusted to compare with values appropriate for the radar equation. The recorded numbers are dBW for a single antenna element near the center of the receive array assuming a point target source; in our Figure 2c example, the levels that should b used as receiver input for our simple radar equation require addition of 19 dB. T single frequency limitation of the ARD can be reduced by using WSBI data. The WSB output of CNR versus range and frequency can be adjusted to correspond to that of the ARD CNR at the ARD operating frequency. However CNRs from the WSBI will not include any SDC effects.

RADARC is a monthly median prediction model, making predictions of hourly behavior for the month and solar activity specified. Thus the prediction, whether for the first or last day of the month, is the same because the prediction is to be interpreted as the median of all the days in the month and not necessarily representative of any individual day. The skywave propagation path is notable by its variability. CNR levels will vary in a few minutes time by 10 dB or more, an many targets will show more extreme variation. We emphasize that comparisons are between a median model and individual or sets of data samples.

Observations and Comparison with Model

Electron Density Profiles. Figure 2a gives a ROTHR quasi-vertical sounding example. In addition the median RADARC sounding is plotted as open square box points. The closed square points show the RADARC sounding after adjusting critica frequencies, heights, and layer thickness to approximate the ROTHR sounding. In this case the RADARC parabolic electron distribution is an adequate match to the

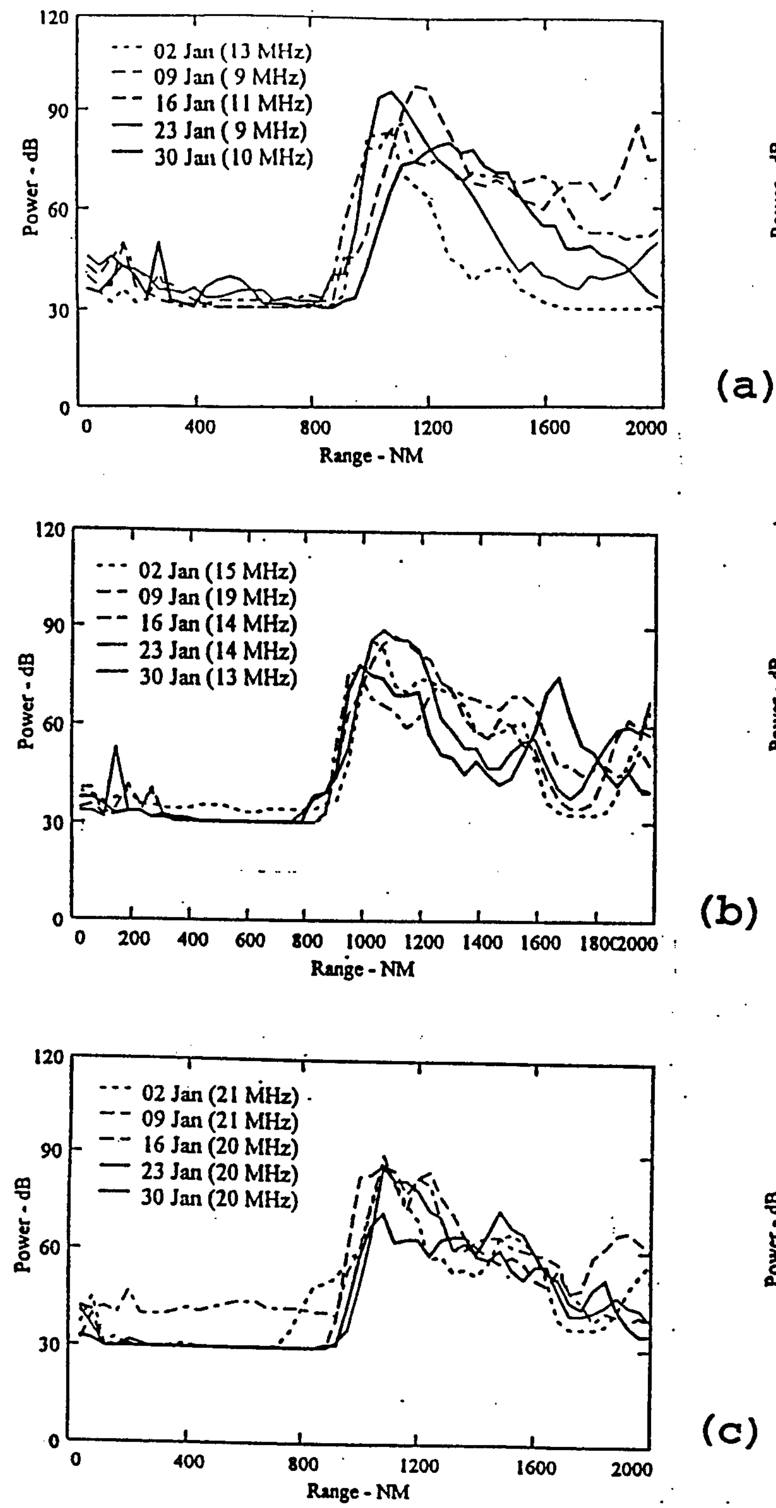


Figure 3. WSBI backscatter level versus range is given for the five collection days in January using a frequency selection that gives similiar range illumination at: **(a)** 0700Z; **(b)** 1200Z; and **(c)** 1800Z.

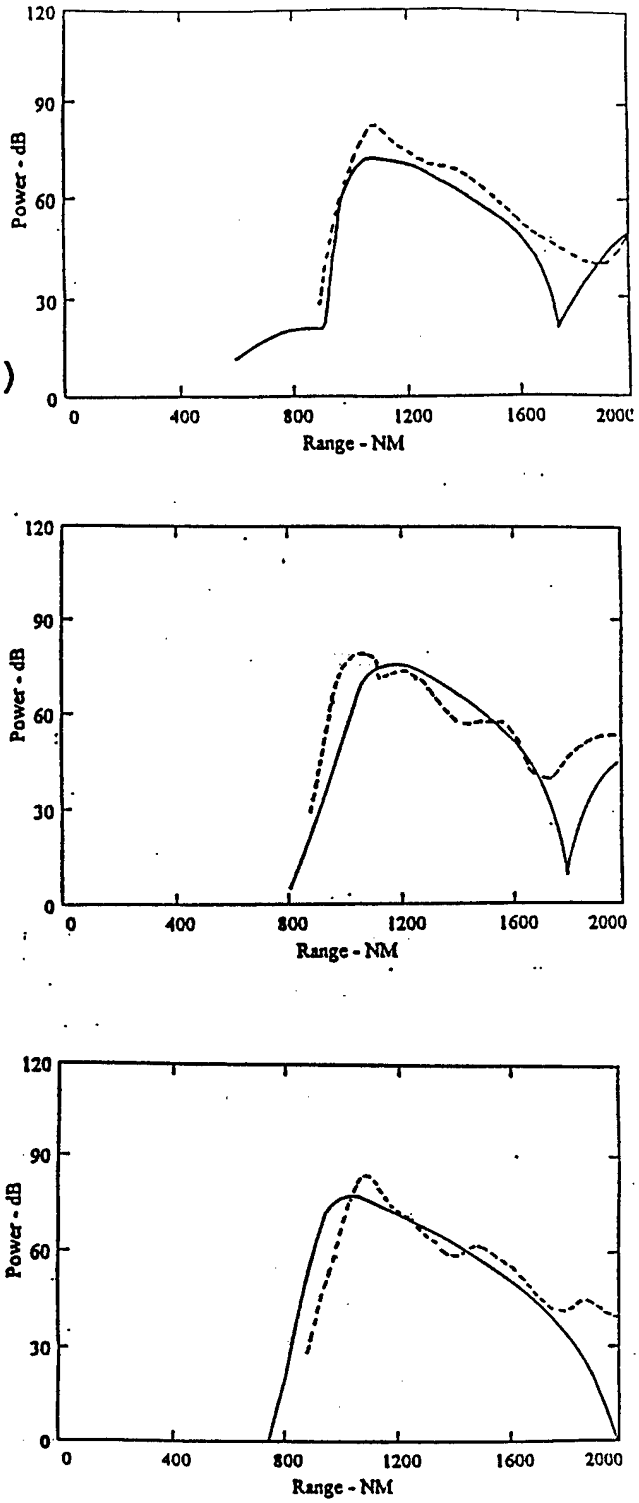


Figure 4. The median of Figure 3 backscatter levels versus range is plotted as a dashed line. The RADARC level is plotted as a solid line using frequencies: **(a)** 10 Mhz at 0700Z; **(b)** 14 Mhz at 1200Z; and **(c)** 20 Mhz at 1800Z.

actual sounding. Note that RADARC uses fxF2 instead of foF2 for a better match to the leading edge of the backscatter range. In 38 soundings distributed over all times in January the parabolic approximation was judged good for 15 samples; in 1 samples the parabolic distribution provided a poor fit; and in three cases the sounding could not be scaled.

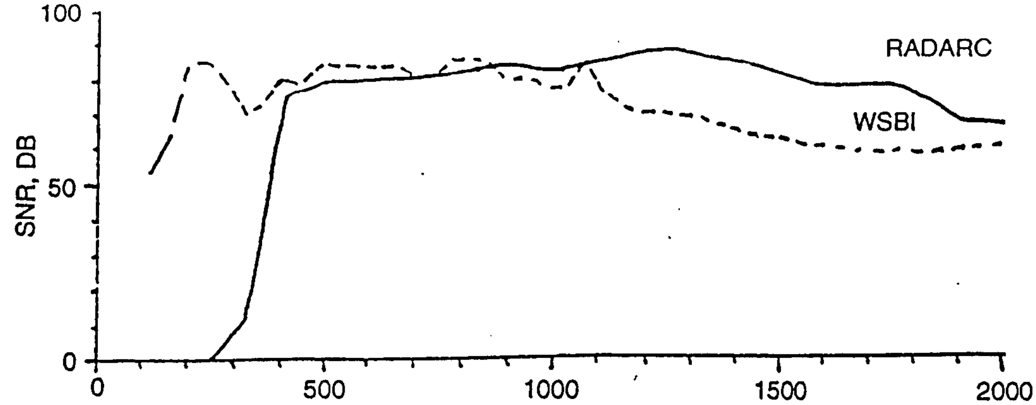
Daily Variability. Figures 3a, 3b, and 3c taken from WSBI soundings at the sam hours (0700, 1200, and 1800 UT) for the five collection days in January give an indication of variability of the skywave path. The frequencies were selected to give about the same skip zone depth and useful surveillance starting at about 1000 nmi, that is the frequency selection was made appropriate for radar coverage of ranges starting about 1000 nmi and out a few hundred miles. The WSBI CNR has been increased by 30 dB to make it coincident with the corresponding ARD clutter to environmental noise ratio. We must adjust in this fashion since the WSBI noise is environmental, and fortunately the model and actual environmental noise are in fa agreement (McNeal 1996). Because of this, comparisons drawn from the WSBI data should be interpreted as that of received power, that is, no SDC effects are treated. These five day samples are hardly adequate to describe a monthly median, however they are distributed over the month and do give an indication of variability. If 1200 nmi is selected as a useful range, daily variation extremes signal level are about 30 dB at 0700 and 20 dB at 1200 and 1800 UT. Note also tha the required frequency varied over 6 MHz at 1200 UT. It should be kept in mind th the radar ARD levels will not be this variable since more smoothing is employed. Even though 30 days would be desirable the five day medians are compared with RADA in Figures 4a, 4b, and 4c. For RADARC, 150 kW transmitter power, 9 dB system loss and a 31 dB scattering coefficient (after OTH enhancement) were used. None of the numbers are known accurately, and the comparatively small scattering coefficient w based upon an estimate that the sea might not be well developed in January. For a these reasons we should be cautious about absolute number comparison. Several features of the model can be seen by these plots:

The above-the-MUF treatment provides a leading edge backscatter start that i realistic;

The general shape of the model over 1000 to 1600 nmi is similar to data; an

The model abrupt cutoff at the horizon is not seen in the data.

In the available ARD map data the frequency selection was often low, such that the skip zone was short, many times less than 500 nmi. Under these conditions the RADARC predicted backscatter level fell off with range faster than observation; this is due in part to the incorrect horizon behavior mentioned above. In the 200 nmi range processed this means that there is a multiplicity of hops and extensive multipath. Since HF radars generally select frequency to maximize sensitivity in t footprint of interest, from shortly after the skip zone out several hundred miles, the model falloff with range might not be considered an important defect. However when very long range ambiguous clutter occurs it is desirable to have good long range estimates. The 10 Hz waveform repetition frequency (WRF) for the examples treated here eliminated any ambiguous SDC.



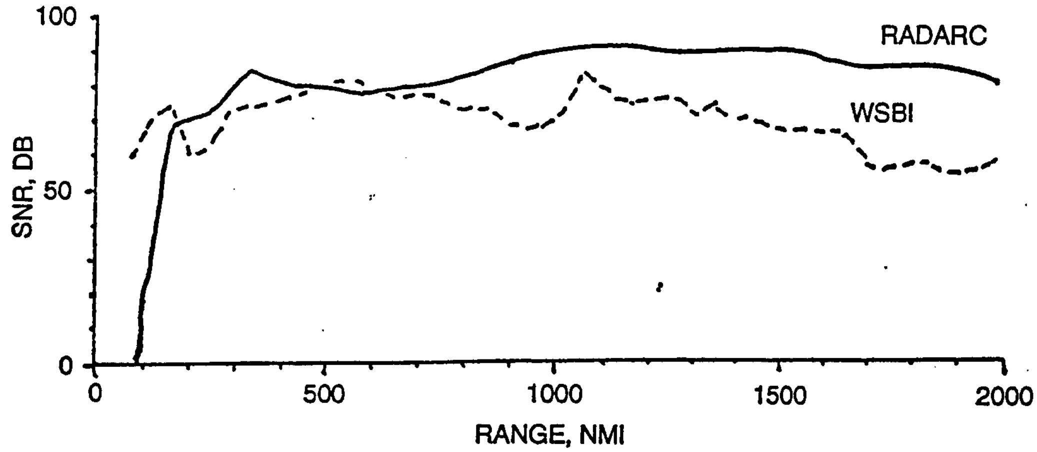


Figure 5. RADARC and WSBI maximum SNRs over 5 to 28 Mhz versus range are given: the top plot is for 0700 UT; and the lower plot is for 1800 UT. Noise levels include no SDC and were similiar.

Maximum Power Sensitivity. One of the available data reductions was a ROTHR-RADARC comparison of peak clutter levels derived from WSBI soundings. As examples, January 2 1994 day and night plots of the model prediction and the WSBI indication are given in Figure 5. As before although these plots are given as CNR, the comparison should be considered that of received power. The noise for the model was from tables and for the WSBI from the Spectrum Monitor; both are environmental noise and generally similar. The level from the WSBI has been adjusted to correspond with a companion ARD map in order to effect an absolute comparison. At each range, the levels indicated are the maximum found over the 5 to 28 MHz frequency interval. The trend here is for the RADARC model to become optimistic with increasing range. Although not shown, this trend does not continue as we go to distances requiring multiple hops. This is in contrast with the single frequency behavior exhibited by Figures 4a, 4b, and 4c which shows the model one hop prediction to become pessimistic with increasing range. In summation:

> Predicted maximum received power level versus distance behaves as observation from short to medium ranges but becomes optimistic for the longer 1 hops.

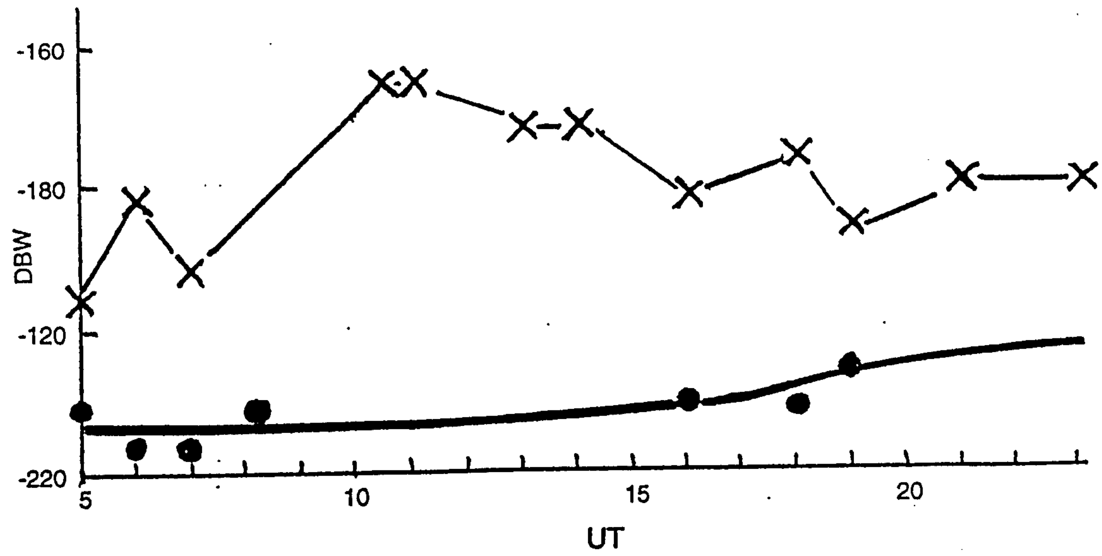
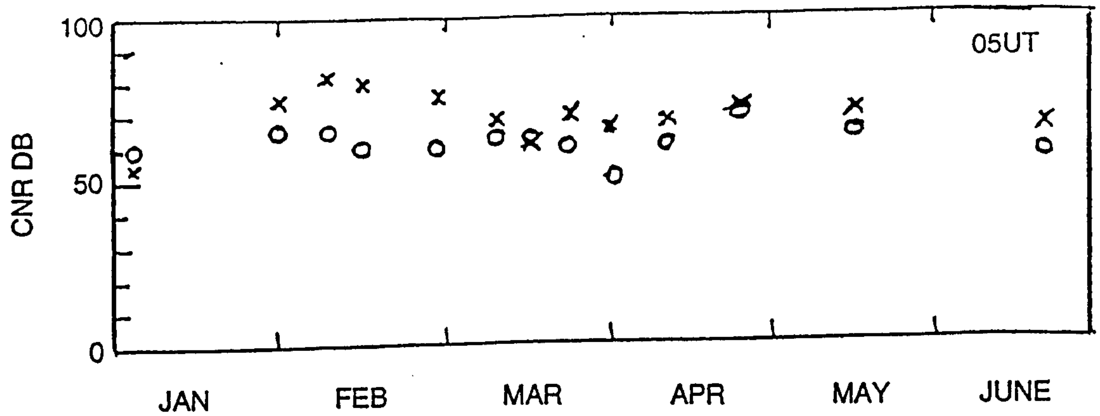


Figure 6. Noise and/or SDC level is plotted versus Universal Time for 2 January 1994. The curve with X points is the level at WRF/4. The black dots show minimum levels from the ARD maps where no SDC was noted. And the solid curve is derived from the Spectrum Monitor data.

Noise and SDC. On January 2 the radar frequency selection was made to provide range coverage from short to medium ranges over the 0500 to 2300 UT period. Frequency selection varied from 5 MHz during the predawn period to 17 MHz in the afternoon. Figure 6 plots noise or SDC levels taken from ARD maps as shown earlier in Figure 1c We emphasize that these levels were read from plots as shown in Figur 1c, and therefore the accuracy is limited. In addition Spectrum Monitor measured noise was available (McNeal 1996). The solid curve is Spectrum Monitor noise which has been referred to the same level as that of the ARD maps. The black dots are noise levels taken from the ARD maps at ranges where no SDC was discerned; this noise agrees fairly well with the Spectrum Monitor noise. The plot with X points is of noise/SDC at 2.5 Hz Doppler; these values were selected from the radar range that had the highest level noise or spread-Doppler clutter which was also the range of maximum clutter level. A Doppler of 2.5 Hz corresponds to a relative speed of 146 knots for 5 MHz operation and 43 knots for 17 MHz. The 2.5 Hz Doppler level noise may seem too harsh for calculating CNR, however it has realism when using th low-WRF feature to avoid range folding equatorial clutter. The morning period showed the poorest performance potential. For this January example SDC always inhibited radar performance at the ranges of maximum sensitivity being most severe in the morning and then diminishing throughout the day. The 2 January data was use because radar operating frequency selection was considered the most realistic available, not because it was considered typical, and it may have been a severe SDC day.

Environmental noise observed is similar to that of the model.

SDC at 2.5 Hz Doppler degraded performance potential by 15 dB at best and 45 dB at worst at the range of maximum received power sensitivity.



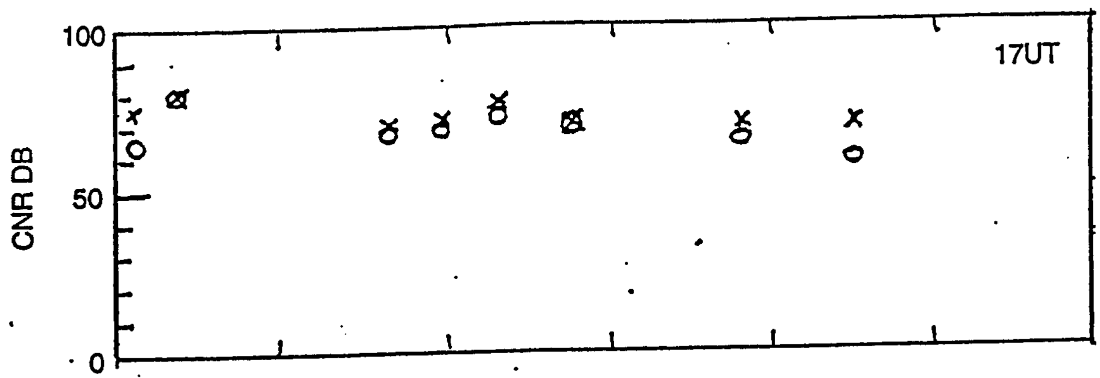


Figure 7. Selected CNR values are plotted over the seasons for 05 UT and 17 UT.The ROTHR levels are given as O points and were limited to examples where radar frequency selection was appropriate for the range. The corresponding RADARC value is marked as an X

CNR with Season. To provide an indication of model performance over the seasons, for the January through June period we compared RADARC median CNR predictions with ROTHR observations. The approach used was more selective than for the 2 January day. The ROTHR data points used were near maximum CNR level and when the frequency was reasonable for normal radar operation. Because of the radar frequencies used, no data came from the longer ranges. In addition the radar CNR is different from that used earlier in that it is the ratio between the maximum level and the minimum level over Doppler. Generally the maximum is near zero Doppler and the minimum near WRF/2 (5 Hz), and almost always this minimum level is smaller than that of 2.5 Hz. The data available was for 0500 UT (night) and 1700 UT (day); neither of these times coincided with the period of worst model performance on 2 January.

Day samples indicate the model to be slightly optimistic.

Night samples, especially in February, show serious model excess in estimates.

Conclusions and Discussion

For the nominal one hop distance region running from 300 to 1600 nmi, RADARC provides useful medians for received power. In the one hop to two hop transition region and at the longer ranges, predictions do not agree with observations. In part the deficiencies are inherent when using geometric ray paths. RADARC's empirical 'above the MUF' provides a treatment for the transition from skip region to the junction frequency, but the model performance in the horizon region needs improvement. Although not shown in the data studied here, the model does not predict the high amplitude very long range clutter that is frequently observed. For the other part of CNR prediction, noise, the contributions due to atmospherics and the Galaxy have been extensively examined (McNeal 1996). At both the Amchitka and Virginia radar locations the CCIR 322 (1988) description agrees fairly well with observation. However CCIR 322 does not take into account variability with th Solar cycle that in fact exists. The more important disagreement between radar experience and the model is in the SDC or multiplicative noise.

For skywave radar employed for surveillance of the nominal one hop region th RADARC model provides good prediction of signal strength behavior.

The noise model generally agrees with observed atmospheric and galactic nois

Daytime SNRs should be good for the higher speed targets. Adequate treatmen of SDC especially at night is the serious deficiency.

Model Enhancements and Status

Capabilities for improving radar performance estimates and for analysis of observations have been studied. The following augmentations to path determination and predicting signal strength have been incorporated into RADARC:

A SDC model has been added based upon Spread F distribution maps.

The virtual height technique has been extended to permit 5 hops in order to include the equatorial region.

A tilt effect treatment has been included as an option when using virtual heights.

Chris Coleman's 2-d ray trace code has been implemented providing a true height alternative for range finding.

These added features have considerably improved our ability for performance analysis, however at very long ranges we still do not estimate signal levels as strong as those that are observed. This failure is not necessarily all due to our radar equation and path trace techniques; the equatorial region ionosphere needs improvement.

For the other part of SNR prediction, noise, the contributions due to atmospherics and the Galaxy have been extensively examined (McNeal). At both the Amchitka and Virginia radar locations the CCIR 322 description agrees fairly well with

observation. The important disagreement between radar experience and the model in the SDC or multiplicitive noise. Our work in this area has consisted of developing a SDC model based on spread F maps (Davis) and in comparing trans-ionospheric scintillation derived maps with the spread F maps. The testing with this model has indicated:

For the equatorial region, general location agreement between the high probability of spread F and occurrence of SDC.

In the one and two hop region some coincidence exists between spread F and SDC.

Future Data Analysis

We have developed new tools to extract, display, and analyze ROTHR data. This capability will enable more thorough and much faster studies than have been described here.

Recommendations

Analysis of the same features that have been described here is recommended on a new data collection with the following type radar operation:

1) radar frequency selections to maximize sensitivity at a short, medium, and long range;

2) add multiple higher WRFs.

Then use the analyzed results in:

Developing an improved transmission path method and a better equatorial ionospheric model.

Assembling an empirical SDC description and developing a model for incorporation in RADARC

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